APPENDIX D-3. VENTING ISSUES IN GAS-FIRED WATER HEATERS

TABLE OF CONTENTS

TABLES

FIGURE

APPENDIX D-3. VENTING ISSUES IN GAS-FIRED WATER HEATERS

This Appendix summarizes the available data on the impacts of high-efficiency water heaters on residential house venting systems.

D-3.1 INTRODUCTION

Use of high flue-loss efficiency gas-fired water heaters (both natural gas and LPG)[a] with existing venting systems that are not designed for lower temperature flue gases can potentially lead to excessive corrosion and failure of the vent system in certain situations. The U.S. Department of Energy recognizes this potential problem and incorporates into the efficiency standards analysis costs of venting modifications in the total installation costs for gas-fired water heaters.

Venting problems are not unique to gas-fired water heaters; other gas-fired appliances have similar problems. The gas industry, through research sponsored by the Gas Research Institute (GRI), has identified and established venting guidelines for high-efficiency gas furnaces.[1] Although there are no venting guidelines for gas-fired water heaters, research studies by the gas industry have evaluated the upper limits of flue-loss efficiency.

This appendix summarizes the findings of previous studies on the impacts of high-efficiency water heaters on vent systems. We also summarize results from two studies conducted by Pacific Northwest National Laboratory (PNNL) to estimate the cost of relining exterior masonry chimneys with corrosion-resistant material and the cost of replacing a single-wall vent connector with a double-wall vent connector. In addition, this appendix also summarizes the input received from utilities and others that have installed high-efficiency water heaters.

D-3.2 BACKGROUND INFORMATION

D-3.2.1 Relationship Between Flue-Loss Efficiency and Recovery Efficiency

Flue-loss efficiency (also referred to as "thermal efficiency" in the older literature; the proposed ASHRAE Standard 90.1-1989R correctly uses thermal efficiency to refer to recovery efficiency) is defined as the ratio of input energy minus the energy lost through the flue in the exhausted combustion products to input energy.

Recovery efficiency (RE) is the percentage of energy transferred to the hot water from input energy. It takes into account the amount of the energy that is lost through the flue and other parts of the water heater, such as jacket and fitting losses. Therefore, RE is always less than flue-loss efficiency for a given water heater.

---

[a]Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of physical and efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

Flue-loss efficiency is the key parameter used to estimate the amount of condensation that can occur in a vent system because higher flue-loss efficiencies mean lower flue gas temperatures. The DOE test procedure for rating residential-sized water heaters does not measure this key parameter; it measures the RE instead. Therefore, we must understand the relationship between flue-loss efficiency and RE to estimate flue-loss efficiency from the DOE test procedure results. A 1991 Gas Research Institute (GRI) study suggests that most water heaters have an RE that is about 3% less than the flue-loss efficiency.[2] The same study notes that this number is a guideline and that individual appliance efficiencies can vary widely. The TANK water heater simulation program developed by GRI to evaluate design options for gas-fired storage water heaters also predicts the difference between the two efficiencies to be at or less than 3%.[3]

The gas industry has been using the 3% difference since 1990; however, in 1998, the gas industry informed DOE that the difference between the two efficiencies may be greater than 3%.[4] This claim is based on six tests of water heaters that GRI reviewed which showed the difference between the two efficiencies to be between 3% and 6%.[5] In these six tests, the flue-loss efficiency was measured in the laboratory and the recovery efficiency was inferred from the Gas Appliance Manufacturing Association (GAMA) catalog for the models tested. When DOE requested the test data for review, GAMA denied the request, stating that the tests were incomplete and, therefore, inconclusive. The gas industry has recommended additional tests to verify the new data.

DOE noted these concerns. However, because of a lack of sufficient data that conclusively show the difference between recovery and flue-loss efficiencies to be higher than 3%, DOE decided to rely on TANK predictions and the industry-established guideline. It is important to note that in the case of higher efficiency water heaters, with lower jacket and fitting losses, the differences between recovery and flue-loss efficiencies shrink.

D-3.2.2 Categorization of Gas Appliances

The gas industry uses the same gas appliance venting system categories for water heaters as for gas furnaces. This categorization helps installers to match the proper vent system to an appliance.[2]

A Category I appliance is defined as an appliance that has a flue-loss efficiency of less than 83% and operates under negative pressure in the vent. Most water heaters sold today are classified as Category I appliances. Most Category I appliances rely on the natural draft of their hot combustion products for venting. Some, however, rely on fans or blowers to overcome the flow resistance through a heat exchanger and push or pull the combustion products through the appliance, although the vent still operates under negative pressure.

Appliances that have a flue-loss efficiency of greater than 83% and operate under negative pressure are classified as Category II appliances. None of these are currently on the market. Category III appliances have flue-loss efficiencies of less than 83%, but operate under positive vent system pressure. Category IV appliances operate under positive pressure, but have flue-loss efficiencies greater than 83%.

All Category III, and IV appliances have venting requirements specified by the manufacturers. These units, in general, cannot use existing vent systems without major modifications. Category III units are permitted to vent side-ways, but need pressure-tight vent systems. Category IV units require a condensate drain, corrosion-resistant vent material, and pressure-tight vents.

Most gas-fired water heaters sold today are classified as Category I appliances because their flue-loss efficiency is equal to or less than 83%, and they operate under negative vent system pressure. The maximum flue-loss efficiency corresponding to the design options considered in this analysis is 83% (or an RE of 80%) and do not require forced venting. Water heaters of the design with the maximum proposed flue-loss efficiency in this study are still Category I appliances.

D-3.3 SUMMARY OF PREVIOUS STUDIES

This section summarizes previous studies by gas industry that deal with specific issues related to masonry chimneys, vent connectors, and various scenarios of installation of high-flue-loss efficiency (>80%) water heaters and modifications that may be required to avoid excessive wet-times in the vent systems.

Summary of Previous Studies Summary of Previous Studies

Masonry chimneys have to be wet for a significant period of time, over 1000 hours/year, for any damage to occur. A 1994 GRI report estimated that 53% of U.S. residences have common vent systems for water heaters and furnaces.[6] With increased minimum furnace efficiency requirements (since 1992), most replacement furnaces now have higher efficiencies than the units they are replacing. Although masonry chimneys are quite resilient to corrosion, relining may be necessary in some cases when the existing low flue-loss efficiency furnace is replaced with a high-flue-loss efficiency furnace. Because furnace on-times are significantly longer than water heater on-times, masonry chimneys rely on the furnace to dry any condensate deposited by the water heater. In high-flue-loss efficiency furnaces, flue gas temperatures are lower, which increases the potential for excessive wet-times in the chimney. The occasional firing of a residential water heater common-vented with a furnace has only a minor impact on the overall wet-time of an exterior masonry chimney.[7] Therefore, there may not be an additional cost associated with relining or changing existing vent systems when a higher efficiency Category I water heater replaces an existing Category I water heater.

Various situations resulting from the replacement of gas-fired water heaters and furnaces are discussed in the following sections.

D-3.3.1 Replacement Installations

Most water heaters sold today are for the replacement market. Therefore, in some cases, replacement of a low-flue-loss efficiency (< 80%) water heater with a high-flue-loss efficiency water heater (80% to 83%) into an unmodified existing vent system may lead to excessive wet-times and therefore to vent system corrosion. In almost all replacement situations, there are vent systems and reliners on the market to meet the venting requirements for installing high-flue-loss efficiency water heaters. In fact, there are no technological barriers to using high-flue-loss efficiency water heaters in a replacement situation.

D-3.3.1.1 Two-Appliance Configuration

In the following section, a two-appliance configuration common venting into a masonry chimney is described and the effect on the venting system when the base case water heater (EF=0.86) is replaced with a high-efficiency unit is discussed. All the information is from GRI reports. The findings are summarized in Table D-3.1.

The basic configuration is assumed to have two natural-draft appliances, a furnace and a water heater, venting into a common vent system. The flue-loss efficiency of each of these units is assumed to be less than 80%. The vent connectors are assumed to be single-wall metal connectors and the vent to be an exterior masonry chimney that is properly sized.

If the replacement water heater is equipped with a draft hood and has a flue-loss efficiency no greater than 80.5%, the new water heater can continue to vent into the existing vent system.

If the flue-loss efficiency of the replacement water heater exceeds 83%, the exterior masonry chimney may need relining in most U.S. climate zones (see Table D-3.2 and Figure D-3.1). If the flue-loss efficiency of the replacement unit exceeds 80.5% but is less than 83%, relining may be needed for some installations (depending on the climate, the possibility of backdraft, and other factors).

When a new high-flue-loss efficiency (83%) furnace with fan-assisted combustion vents into an existing chimney, relining the chimney is recommended in all U.S. climate zones, except for Zone 5.[6] The cost of relining should be assigned to the furnace and not to the water heater.

When replacing both the existing water heater and furnace with high-flue-loss efficiency models, the exterior masonry chimney has to be relined in all climate zones if the flue-loss efficiency of either of the two appliances exceeds 83%, and in some zones if the flue-loss efficiency of the water heater exceeds 80.5% (but is less than 83%). As mentioned earlier, furnace operation influences the wet times in the masonry chimney more than water heater operation. Therefore, in most cases, if the water heater flue-loss efficiency does not exceed 83%, the cost associated with relining should be assigned to the furnace and not to the water heater.

When an existing commonly vented furnace is replaced with a high-flue-loss efficiency furnace requiring its own vent system, it “orphans” the water heater (i.e., the water heater is left alone to vent into the exterior masonry chimney). The existing chimney should be relined in all regions because it is oversized for the water heater, but the cost for relining is part of the furnace replacement.

Table D-3.1 Recommendations for Relining Exterior Masonry Chimneys in a Two-Appliance Configuration

Option	Comment
Base case: both furnace and water heater with flue-loss efficiency less than 80%	No relining is necessary.
Replace base-case water heater with 80% flue-loss efficiency unit	No relining is necessary.
Replace base-case water heater with 83% flue-loss efficiency unit	Relining may be needed for some installations in some climate zones.
Replace base-case furnace with 83% flue-loss efficiency unit (fan-assisted) without replacing base-case water heater	Relining of the chimney is recommended in all climate zones except Zone 5.
Replace both base-case water heater and furnace with high-flue-loss efficient units	If the flue-loss efficiency of the water heater exceeds 80.5% but is less than 83%, chimneys in some climate zones may need relining. If the flue-loss efficiency of either appliance is above 83%, relining is recommended in all zones. In most cases, the cost of relining should be assigned to the furnace replacement.
“Orphaned” water heater	Relining is recommended in all climate zones, but the cost for relining has to be assigned to the furnace replacement and not the water heater

Table D-3.2 Climate Zones of the United States

Climate Zone	Examples of Cities Included in Zone
1	Billings MT; Minneapolis MN; Augusta ME
2	Omaha NE; Akron OH; Boston MA
3	Wichita KS; Lexington KY; Baltimore MD
4	San Francisco CA; Memphis TN; Raleigh NC
5	Honolulu HI; New Orleans LA; Miami FL

Source: U.S. Department of Energy-Energy Information Administration, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures,* DOE/EIA-0625(95), 1998.

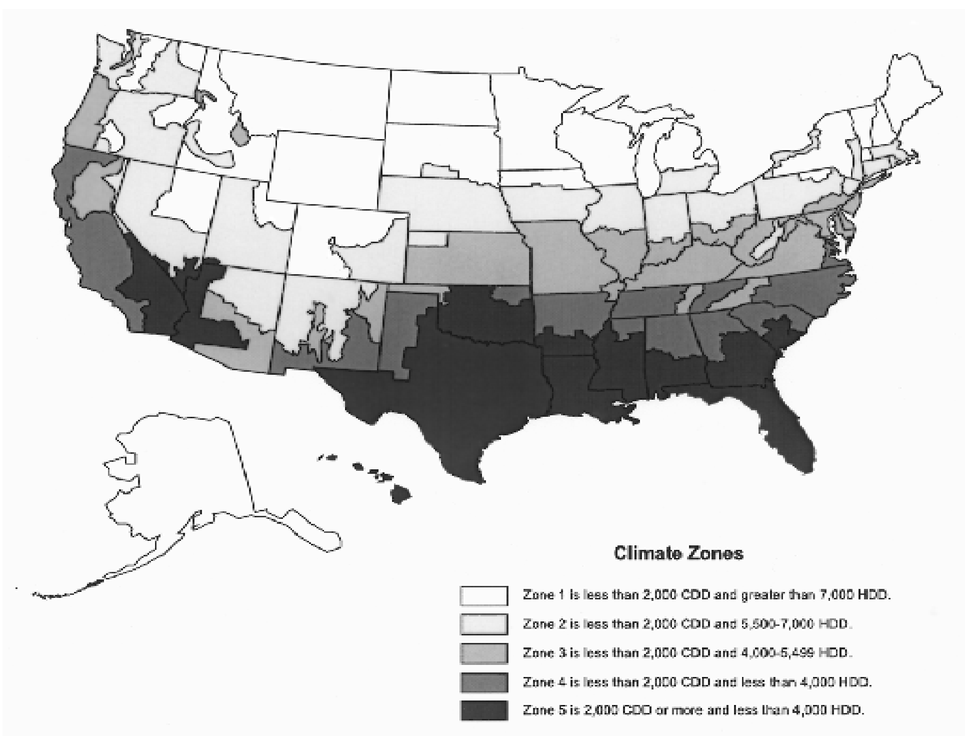

Figure D-3.1 Climate Zones of the United States

D-3.3.1.2 One-Appliance Configuration

In the following section, an installation with only a water heater venting into the vent system is described and the effect on the vent system when the base case unit is replaced with a high-flue-loss efficiency unit is discussed. Findings are summarized in Table D-3.3.

The basic configuration is assumed to have a natural draft water heater venting into an exterior masonry chimney. The flue-loss efficiency of the unit is assumed to be less than 80%. The vent connectors are assumed to be single-wall metal existing, and the vent is assumed to be properly sized.

If the replacement water heater is equipped with a draft hood and the flue-loss efficiency is no greater than 80%, the new water heater can continue to vent into the existing vent system.

If the flue-loss efficiency of the replacement water heater exceeds 83%, the exterior masonry chimney will need relining in some climate zones. If the flue-loss efficiency of the replacement unit exceeds 80% but is equal to or less than 83%, relining may not be necessary in most zones.

Table D-3.3 Recommendations for Relining Exterior Masonry Chimneys in a One-Appliance Configuration

Option	Comment
Base case: flue-loss efficiency of the water heater is less than 80%	No relining is necessary
Replace base-case water heater with 80% flue-loss efficiency unit	No relining is necessary
Replace base-case water heater with 83% flue-loss efficiency unit	Relining may be needed in some climate zones

D-3.3.2 New Construction

Most water heaters with flue-loss efficiencies greater than 83% require manufacturer-specified vent systems. Therefore, in new construction with a proper vent system, there is no upper limit on flue-loss efficiency. Some issues related to new construction installations are:

- Use of high-flue-loss efficiency (80% or higher) water heaters does not create venting problems because there are vent systems currently on the market that will handle low-temperature flue gases and any potential corrosion from the condensate.
- There are no general guidelines (similar to the National Fuel Gas Code (NFGC)[8] for Category I appliances) for installing vents for high-flue-loss efficiency water heaters.
- Manufacturers of high-flue-loss efficiency water heaters are required to provide vent installation instructions.

- Installers are not always aware of potential venting problems and availability of alternate vent systems.

D-3.3.3 Vent Connectors

The portion of the vent system connecting the gas appliance draft divertor or draft hood to the vent is called a vent connector. Particular vent connector configurations and installations can produce "worst-case" scenarios in which the vent system degrades and corrodes at a faster rate than in other configurations or installations.

A worst-case scenario occurs when the configuration contains a very long (> 15 ft) vent connector lateral because, according to a key GRI study,[7] the key variable in determining the appliance's efficiency limit is the wet-time, and the vent connector wet-times are more critical than the vertical vent wet- times.

GRI reports that a single-wall vent connector limits the flue-loss efficiency of gas appliances to 80% in a worst-case installation. A worst-case installation is defined as a water heater with a 30-gallon tank and an input-firing rate of 25,000 Btu/hr with a 15-ft lateral attached to a 15-ft vertical. Although this is a worst-case scenario, NFGC limits the lateral length to 10 ft maximum.[8] Therefore, a more realistic worst case might have a flue-loss efficiency limit higher than 80%. Other major conclusions of the GRI report include:

- Higher flue-loss efficiency units can be allowed if the draft-hood diameters are increased slightly, for example, from 3” to 4”.
- Use of Type-B metal vent connectors with Type-B metal vents will allow for higher minimum flue-loss efficiency (up to 84% from 80%). If a water heater has a flue-loss efficiency of 84% or higher, a condensate drain may also be needed.
- Type-B metal vent connectors and Type-B metal vents are also recommended for water heaters installed in unheated spaces (such as in garages, basements, or outdoors).
- GRI estimates the upper-limit flue-loss efficiency to be between 83.5% and 84% for a typical house. A typical installation uses a single-wall metal vent connector and has a capacity of 35,000 Btu/hr with 5-ft lateral length and 20-ft vertical height.

D-3.4 ISSUES RELATING TO BACKDRAFTING

Residences can be depressurized because of tight construction, operation of exhaust equipment, imbalanced air distribution systems due to improper installation of duct and vent systems, or local weather.[9] Fuel-fired water heaters equipped with draft hoods depend on the hot flue gases creating thermal buoyancy to exhaust combustion products through the chimney. If house depressurization exceeds the natural draft or thermal buoyancy, the water heater can backdraft, i.e., combustion products enter indoor spaces rather than exiting through the vent systems. The current potential for depressurization-induced backdrafting and spillage in the U.S. housing stock is not well known, nor is the actual frequency or severity of such events.

Although backdrafting is primarily caused by depressurization (which is unrelated to the efficiency level of the water heater), increasing the efficiency of the water heater may increase backdrafting slightly, because an increase in efficiency lowers the flue gas temperatures, thereby reducing buoyancy. However, the primary cause of backdrafting is depressurization of the residence. DOE understands that backdrafting is a potentially serious problem and that backdrafting may have a detrimental effect on occupants. However, DOE concludes that the design options being considered for fuel-fired water heaters do not by themselves, depressurize residences.

D-3.5 NATIONAL FUEL GAS CODE REQUIREMENTS[8]

According to NFGC 54 (ANSI Z223.1), Type-B (or Type-L) vent systems and Type-B vent connectors are needed for any portion of the vent system or any vent connectors that are exposed to cold conditions (i.e., those in unconditioned spaces such as in the attic, crawl space, unconditioned garage.)

Also, according to NFGC 54 (ANSI Z223.1), Type-B vent connectors are required if the vent connectors are located less than 6" from any combustible material such as passing through a wall.

D-3.6 REVIEW OF UTILITY DSM PROGRAM

Avista Corp. (formerly Washington Water and Power) installed more than 20,000 gas-fired appliances (both water heaters and furnaces) as part of a fuel-switching program in the Pacific Northwest (Washington and Idaho) over a period of five years (1992 – 1997). The program required a water heater with an EF of 0.60 or higher for a 50-gallon tank and 0.62 or higher for a 40-gallon tank. Most units installed had an EF of 0.60 or 0.62. In general, an EF of 0.60 corresponds to an RE of 78% and a 0.62 EF corresponds to RE of 78% to 80%, although there may be exceptions.

A significant number of the installations (more than 80%) were power-vented appliances while the rest were natural-draft equipped (again both water heaters and furnaces). The natural draft equipped units were generally installed in homes that had an existing gas appliance with a vent system. In most cases, no modifications were made to existing vent systems, including the vent connector, even when high-efficiency water heaters were installed. A few Type-B vent systems, including connectors, were installed to meet the NFG code (for example, in unheated spaces, where there was lack of proper clearance, etc.). The program managers at Avista Corp. have indicated that they have not received any complaints of vent corrosion even after five years of operation.[10]

D-3.7 VENT MODIFICATION COST SUMMARY

Because there are a significant number of masonry venting systems in the U.S., DOE recognizes that there could be a problem if energy-efficiency standards result in gas-fired water heaters with high-flue-loss efficiencies (>80%). Therefore, the Department incorporates the costs of venting modifications in water heater installation costs, where necessary. Relining the vent system and installing double-wall vent connectors may be necessary when some existing gas appliances (water heaters and furnaces) attached to exterior masonry chimneys are retrofitted with higher flue-loss efficiency units (flue-loss efficiency greater than 80%).

In this section, the cost estimates obtained by DOE for relining exterior masonry chimneys are presented and compared with the costs published in the 1991 GRI report.[2] The primary reason for the comparison is to verify that the costs reported in the 1991 report are still valid (after adjusting for inflation).

Two consultants to PNNL (one from Portland, OR and the other from Grand Rapids, MI) collected two separate sets of data (herein called Data Set 1 and Data Set 2) to estimate the cost of relining the vent system and the cost of Type-B vent connectors.

Data Set 1 Results. The Portland contractor conducted a quick nationwide survey of chimney sweeps that actively reline chimneys for gas appliances. All operate successful and relatively large businesses; several serve on the Board of Directors of the National Chimney Sweep Guild. Nine responses to the request for information were received – seven from the East, one from the Midwest, and one from the West.

The sweeps were asked to provide materials and labor costs for relining exterior masonry chimneys with the three most commonly used relining materials: Aluminum (flexible), Type-B metallic, and AL29-4C Stainless Steel. They were asked to provide separate estimates for one- and two-story houses having either a 4” or a 5” diameter chimney flue. The height of the flue was not specified: the respondents were allowed to use their judgment for what is typical in their region for one- or two-story detached houses.

The average costs of relining the exterior masonry chimneys are summarized in Table D-3.4. The left-hand side of the table provides average costs from all nine responses and the right-hand side of the table provides average costs with the highest and lowest estimates (outliers) dropped. The bottom line shows the cost estimates from the 1991 GRI report (converted 1998$) for the same relining materials.

The GRI cost estimates are based on a baseline vent system with a single-wall vent connector (4” in diameter, 8’ long with two elbows) attached to either a Type-B vertical vent (5” in diameter, 22’ high) or a masonry chimney (also 22’ high from the breaching to the top of the chimney outlet). The relining cost estimates from Data Set 1 are generally higher than those reported by GRI. The discrepancy may be due to the unspecified flue height in the sweeps’ survey and the respondents may have assumed a worst case scenario. The complete data are presented at the end of this appendix in Table D-3.8 (responses I thru IX).

Table D-3.4 Data Set 1 - Summary of Cost Estimates and Comparison with GRI

Vent Diameter/ No. of Stories	Average of All Responses			Average with Outliers Dropped		
	Aluminum *($)*	Type-B *($)*	AL29-4C *($)*	Aluminum *($)*	Type-B *($)*	AL29-4C *($)*
4"/one	689	757	1,040	479	603	893
5"/one	769	840	1,174	558	711	1,049
4"/two	833	940	1,288	602	788	1,146
5"/two	912	1,021	1,434	679	888	1,305
GRI Reported Cost Estimates				505	505	1,285

Data Set 2 Results. The Grand Rapids consultant was asked to estimate the cost for a baseline vent system as specified by the GRI report. The consultant interviewed six installers in Grand Rapids, MI. None had experience with installing Type-B or AL29-4C reliners and therefore only provided cost estimates for relining vent systems with aluminum. The value of $309 represents the average from all six responses and includes materials and labor. This group also provided a cost estimate for replacing single-wall vent connector with Type-B vent connector. Table D-3.5 summarizes the costs collected from Data Set 2. The raw data is shown in Table D-3.8 (responses X thru XV).

Table D-3.5 Data Set 2 – Summary of Cost Estimates

Aluminum *($)*	Type B-Vent Connector		
	8" Length	Elbow (each) *($)*	Labor *($)*
309	52	31	36

Conclusion from Data. The average cost to reline the vent system, with aluminum, in a one-story house with a 5" diameter chimney flue for both Data Sets 1 & 2 is approximately $433. This compares with $505 ($1998) in the GRI estimates.

The GRI cost estimate for replacing a single-wall vent connector with a Type-B double-wall vent connector is $105 (1998$) compared to the survey estimate of $114 (8” length, 2 elbows). DOE used the estimates from the recent two data sets for replacing a single-wall vent connector with a Type-B double-wall vent connector and for relining a masonry chimney.

D-3.8 RECOMMENDATIONS ON VENT SYSTEMS MODIFICATIONS

Vent Costs for Design Options with Recovery Efficiency of less than 78% (or Flue Loss Efficiency less than 81%). For design options with recovery efficiencies less than 78% no vent or connector modifications are recommended.

Vent Costs for Design Options with Recovery Efficiency of 78% (or Flue Loss Efficiency of 80.5%). DOE estimates that only a small fraction of the installations with recovery efficiency of 78% will need to change from a single-wall vent connector to a double-wall or Type-B vent connector. GRI estimated that 75% of the installations with single-wall vent connectors fall under the non-typical (or worst case) installations and therefore, have to be replaced with Type-B vent connectors.[2] The GRI report, however, does not provide adequate background for how the estimate was arrived at.

Using computer simulations, GRI concluded that the limiting efficiency to use a single-wall vent connector in a worst-case vent configuration is 80% flue-loss efficiency.[7] However, the worst case vent configuration that was evaluated violated the NFGC code requirement. The manufacturers always recommended that the water heaters be installed according to the NFGC or local and state codes where applicable. Therefore, the worst case configuration that was evaluated is unrealistic. The same report, however, concludes that a typical vent configuration limits the flue-loss efficiency to 83.5% (80 – 81% recovery efficiency).

Although the limiting flue-loss efficiency for a single-wall vent connector is 83.5% for a typical vent configuration, DOE recognizes the fact that there may be a small fraction of installations that are non-typical. These non-typical vent configurations may require double-wall or Type-B vent connectors to prevent corrosion especially in colder climates.

The fraction of the U.S. housing stock that fall in the non-typical vent configuration category is not known. Therefore, DOE estimated the fraction based on comments provided by the manufacturers, reviewers of the November 1998 draft TSD, conversation with experts in the field,[11] and evaluations from a utility program that promoted high-efficiency water heaters (Avista Corp., formerly Washington Water and Power).[10]

Based on the review of the GRI report, conversations with Avista Corp., and vent installation experts, DOE has concluded that no modifications are needed to existing vent systems in climates similar to that of the Pacific Northwest (approximate heating degree-days at base 65°F (HDD65) (less than 5,000). However, for colder climates (HDD65 $\geq$ 5,000), DOE concludes that a small fraction of the water heaters may need Type-B vent connectors if flue-loss recovery efficiency exceeds 78%. Neither DOE nor the industry at this time clearly knows what fraction of water heaters actually can be categorized as worst-case configurations requiring Type-B vent connectors.

In general, the units with low firing rates (< 25,000 Btu/h) and 3” flue diameter tend to generate more wet-time than the units with high firing rates (> 40,000 Btu/h) and 4” diameter flue vent. A review of shipment numbers indicates that only a small fraction of the installed water heaters have low firing rates (less than 10%).[b] Although low firing-rate water heaters account for less than 10% of the total shipments, DOE assumed that 25% of the installations that have single-wall connectors in climates with over 5,000 HDD65 need to be replaced with Type-B vent connectors. Therefore, the Department included the cost to install a Type-B vent connector when replacing an existing water heater with one that has an efficiency of 78% RE (flue-loss efficiency of 81%) or higher under the following conditions:

- the house is located in one of the U.S. Census regions in the Northeast or Midwest,
- the house is in a cold climate (HDD65 equal to or over 5,000),
- the house was built before 1950,
- the water heater is installed in a conditioned space, and
- the water heater is classified as a worst-case installation (only 25% of the installations are assumed to be worst case).

Regardless of the efficiency level of the fuel-fired water heater, the NFGC requires Type-B vent systems including connectors for water heaters installed in partially or fully unconditioned space or if there is not enough clearance between the walls and the vent system. Therefore, in such situations additional costs due to vent system modifications were not assigned to the design option. Based on the review of the RECS data, DOE inferred that approximately 54% of water heaters are installed in conditioned spaces and the rest are installed in garages or unconditional spaces.

The weighted average national cost of installing Type-B vent connectors is tabulated in Table D-3.6. A range of costs is used in the detailed LCC analysis (see Chapter 9), and the average national cost is used for the engineering analysis (see Chapter 8). DOE would have preferred to estimate the vent modification cost for each climate location separately; but is limited to a regional analysis because the results from the survey conducted by the American Gas Association (AGA) are summarized by regions.[2] This survey details the types of vent systems that exist in the field.

As reported earlier in this Appendix, the cost of installing Type-B vent connectors (including two elbows and a 5' lateral) is \$114 (1998\$). The average national cost is based on installations in the Northeast and the Midwest regions because most populated areas in the West and the South have HDD65 less than 5,000. This is a conservative estimate because the fraction of water heaters that have single-wall vent connectors in the Northeast and the Midwest are greater than the South and the West. Given these assumptions, the average national cost for installing a Type-B vent connector is about \$6.73 (1998\$). For the detailed LCC analysis, the cost range was used if the HDD65 for the house is equal to or exceeds 5,000, the house was built prior to 1950, and if the water heater is installed in a conditioned space.

As mentioned earlier, furnace on-times are significantly higher than the water heater on-times; therefore, masonry chimneys rely on the furnace to dry the condensate deposited by the water heater wherever they are common-vented. The occasional firing of a residential water

---

[b]Shipment data by input rating are not generally available, so the shipments were evaluated based on the tank size.

heater that is common-vented with a furnace has only a minor impact on the overall wet-time of an exterior masonry chimney. Even when a furnace with a flue-loss efficiency of 80.5% is installed, relining is not recommended in most climate zones.[6] Therefore, no relining of masonry chimneys is recommended in any zone for water heaters with a flue-loss efficiency of less than 80% (78% RE).

Table D-3.6 Estimate of Average Cost of Installing Type-B Vent Connectors

Region	Fraction of Homes with Single-Wall Vent Connector*	Fraction of Homes Needing Type-B Vent	Col. 2 × Col. 3 × Cost of Installing Type-B Vent Connectors *($)*	Fraction of Total U.S. Homes with Gas Water Heaters**
Northeast	0.93	0.25	26.51	0.18
Midwest	0.87	0.25	24.80	0.31
South	0.46	0.25	13.11	-
West	0.73	0.25	20.81	-
National	(Cost for Northeast × fraction of homes in Northeast region with gas water heaters + cost for Midwest × fraction of homes in Midwest region with gas water heaters)* fraction of water heaters installed in conditioned spaces (i.e., 54%)			$6.73

* AGA survey results reported by Paul et al., 1991
** 1995 Revised U.S. Census

Vent costs for RE 80% (or flue loss less than 83%): The cost to install a Type-B vent connector (based on the criteria outlined in the previous section) is included in the analysis when replacing an existing water heater with a water heater with RE of 80%.

The impact of the efficiency of a draft- hood-equipped water heater that is common-vented with a furnace on the wet-times is small. Therefore, in mild climates (HDD65 < 5,000), it is assumed that no relining of masonry chimneys is necessary even at the 80% recovery efficiency or 83% flue-loss efficiency. However, in cold climates (HDD65 ≥ 5,000), a few exterior chimneys may need to be relined. It was not clear from this review of the literature what fraction of the chimneys in the cold regions would actually have to be relined.

Since most common-vented water heaters do not impact the overall wet-times of the masonry chimneys, only those water heaters that vent into a chimney by themselves may require chimneys to be relined in cold climates. The number of residences that have common vents vary from a low of 28% (South) to a high of 76% (Northeast), and the number of residences with masonry chimneys vary from a low of 18% (South) to a high of 82% (Northeast). Therefore, about 72% of the water heaters in the South are not common vented and in the Northeast it is about 24%.

Although a fraction of the water heaters that are not common vented may have to be relined, DOE assumed 25% of masonry chimneys in cold climates (i.e., with HDD65 ≥ 5000) have to be relined. The cost of relining masonry chimneys is about $433 (1998$).

For the average national cost of Type-B vent connectors, refer to the previous section. Table D-3.7 describes the weighted average cost estimates for relining masonry chimneys by region. The weighted average national cost is based only on the Northeast and the Midwest regions because most populated areas in the West and the South have HDD65 of less than 5,000. With these assumptions, the average national cost for relining masonry chimneys is about $36.79 (1998$). For the detailed LCC analysis, the appropriate range of costs are used if the HDD65 is equal to or exceeds 5,000 and the house was built prior to 1950.

Table D-3.7 Estimate of Average Cost of Relining Masonry Chimneys in Different Regions

Region	Fraction of Homes with Masonry Chimneys*	Fraction of Homes with Masonry Chimneys Needing Relining	Col. 2 × Col. 3 × Cost of Relining *($)*	Fraction of Total U.S. Homes with Gas Water Heaters**
Northeast	0.82	0.25	88.77	0.18
Midwest	0.62	0.25	67.12	0.31
South	0.18	0.25	19.49	-
West	0.36	0.25	38.97	-
National	(Cost for Northeast × fraction of homes in Northeast region with gas water heaters + cost for Midwest × fraction of homes in Midwest region with gas water heaters)* fraction of water heaters installed in conditioned spaces (i.e., 54%)			$36.79

* AGA survey results reported by Paul et al., 1991
** 1995 Revised U.S. Census

Table D-3.8 Raw Survey Data

		One-Story 4"			One-Story 5"			Two-Story 4"			Two-Story 5"		
		Materials *($)*	**Labor** *($)*	**Total** *($)*	**Materials** *($)*	**Labor** *($)*	**Total** *($)*	**Materials** *($)*	**Labor** *($)*	**Total** *($)*	**Materials** ($)	**Labor** *($)*	**Total** *($)*
Response I	Aluminum	201.00	345.00	546.00	283.00	414.00	697.00	300.00	525.00	825.00	378.00	525.00	903.00
	AL29-4C	731.00	345.00	1,076.00	831.00	414.00	1,245.00	1,104.00	525.00	1,629.00	1,240.00	525.00	1,765.00
	Type-B	221.00	345.00	566.00	278.00	414.00	692.00	318.00	525.00	843.00	411.00	525.00	936.00
Response II	Aluminum	213.20	581.80	795.00	245.25	604.75	850.00	213.20	581.80	795.00	245.25	604.75	850.00
	AL29-4C	751.85	546.15	1,298.00	846.25	551.75	1,398.00	842.11	555.89	1,398.00	949.43	548.57	1,498.00
	Type-B	197.42	600.00	797.42	223.32	600.00	823.32	226.20	600.00	826.20	256.56	600.00	856.56
Response III	Aluminum												
	AL29-4C	245.00	225.00	470.00	285.00	225.00	510.00	435.00	350.00	785.00	443.00	390.00	833.00
	Type-B	90.00	175.00	265.00	110.00	180.00	290.00	146.00	250.00	396.00	170.00	275.00	445.00
Response IV	Aluminum	146.00	300.00	446.00	161.00	300.00	461.00	176.00	400.00	576.00	198.00	400.00	598.00
	AL29-4C	491.00	450.00	941.00	539.00	450.00	989.00	680.00	450.00	1,130.00	755.00	450.00	1,205.00
	Type-B												
Response V	Aluminum	351.72	1,600.00	1,951.72	434.64	1,600.00	2,034.64	387.40	1,600.00	1,987.40	477.06	1,600.00	2,077.06
	AL29-4C	876.72	1,600.00	2,476.72	950.94	1,600.00	2,550.94	1,246.86	1,600.00	2,846.86	1,364.20	1,600.00	2,964.20
	Type-B	264.84	1,600.00	1,864.84	307.46	1,600.00	1,907.46	337.60	1,600.00	1,937.60	394.06	1,600.00	1,994.06
Response VI	Aluminum												
	AL29-4C												
	Type-B	104.44	55.00	159.44	180.00	80.00	260.00				260.00		125.00

Table D-3.8   Raw Survey Data Table - continued

One-Story 4"					One-Story 5"			Two-Story 4"			Two-Story 5"		
		Materials ($)	**Labor ($)**	**Total ($)**	**Materials ($)**	**Labor ($)**	**Total ($)**	**Materials ($)**	**Labor ($)**	**Total ($)**	**Materials ($)**	**Labor ($)**	**Total ($)**
Response VII	Aluminum AL29-4C Type-B	150.00 325.00 300.00	160.00 160.00 160.00	310.00 485.00 460.00	170.00 370.00 370.00	175.00 175.00 200.00	345.00 545.00 570.00	410.00	170.00	580.00	490.00		190.00
Response VIII	Aluminum AL29-4C Type-B	248.31 661.85 315.00	150.00 225.00 275.00	398.31 886.85 590.00	328.70 772.00 460.00	200.00 300.00 300.00	528.70 1,072.00 760.00	283.00 826.44 420.00	150.00 225.00 275.00	433.00 1,051.44 695.00	380.00 932.00 572.00		200.00 300.00 300.00
Response IX	Aluminum AL29-4C Type-B	228.92 423.85	150.00 260.00	378.92 683.85	264.16 839.11	200.00 240.00	464.16 1,079.11	228.92 623.31	150.00 260.00	378.92 883.31	264.16 1,037.03		200.00 260.00
Response X	Aluminum				150.00	225.00	375.00						
Response XI	Aluminum				200.00	125.00	325.00						
Response XII	Aluminum				225.00	125.00	350.00						
Response XIII	Aluminum				200.00	100.00	300.00						
Response XIV	Aluminum				210.00	90.00	300.00						
Response XV	Aluminum				125.00	80.00	205.00						

REFERENCES

1. Gas Appliance Manufacturing Association, *Venting Tables for Category I Central Furnaces,* 1990. Arlington, VA. Supplementary Installation Instructions Distributed with Furnaces Shipped Since September 1990.

2. Paul, D. D., W. J. Sheppard, G. R. Whitacre, R. D. Fisher, A. L. Rutz, D. W. Locklin, J. J. Crisafulli, G. H. Stickford, J. G. Murray, D. K. Landstrom, S. G. Talbert, A. R. Buhr, D. W. DeWerth, C. A. Farnsworth, R. L. Loria, and J. A. Pietsch, *Assessment of Technology for Improving the Efficiency of Residential Gas Water Heaters,* 1991, Gas Appliance Technology Center, Gas Research Institute. Chicago, IL. Report No. GRI-91/0298.

3. Paul, D. D., G. R. Whitacre, J. J. Crisafulli, R. D. Fischer, A. L. Rutz, J. G. Murray, and S. G. Holderbaum, *TANK Computer Program User's Manual with Diskettes: An Interactive Personal Computer Program to Aid in the Design and Analysis of Storage-Type Water Heaters,* July, 1993, Battelle Memorial Institute. Prepared for the Gas Research Institute. Report No. GRI-93/0186.

4. Gas Appliance Manufacturing Association, *personal communication.* Conference calls between GAMA and DOE. March and July, 1998.

5. Paul, D. D. and B. Hemphill, *Briefing on GRI NAECA Water Heater Work for DOE/LBNL/PNNL, Residential Project Advisory Group Meeting, Gas Research Institute,* March, 1998. Berkeley, CA.

6. Phillips, D. B., A. L. Rutz, G. R. Whitacre, and S. G. Talbert, *Venting Gas Appliances into Exterior Masonry Chimneys: Analysis and Recommendations,* 1994, Gas Appliance Technology Center, Gas Research Institute. Chicago, IL. Report No. GRI-94/0193.

7. Talbert, S. G., D. B. Philips, G. R. Whitacre, J. J. Crisafulli, and A. L. Rutz, *Categorization Criteria for Residential Draft-Hood-Equipped Gas Water Heaters,* October, 1995, Battelle. Columbus, OH. Prepared for Gas Research Institute. Report No. GRI-95/0198.

8. National Fire Protection Association, *National Fuel Gas Code -1999 Edition,* 1999. 1 Batterymarch Park, P.O. Box 9101, Quincy MA. Report No. ANSI Z223.1-1999.

9. Koontz, M. D., N. L. Nagda, and D. T. Grimsrud, *Field Protocol for Determining Depressurization-Induced Backdrafting and Spillage from Vented Residential Gas Appliances,* 1996, Gas Appliance Technology Center, Gas Research Institute. Chicago, IL. Report No. GRI-96/0303.

10. Curtis, R., *personal communication.* Avista Corp. Telephone conversation with Srinivas Katipamula, PNNL. March, 1998.

11. Anderson, T., *personal communication.* Indiana Weatherization Program. Talk with Jim Lutz, LBNL. March, 1998.